REAL TIME RETARGETING
PE 0601153N (NRL 015-08)

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LONG TERM GOALS:

The primary goal of this research is to use recently developed numerical methods (including adjoint techniques) to study predictability of atmospheric flows at various scales (synoptic and mesoscale), and identify specific factors, including observational requirements, which can be controlled (in real-time) to provide significant increases in short-range (up to 3 days) forecast skill.

OBJECTIVES:

In many forecast situations, a high percentage of forecast error in operational numerical weather prediction (NWP) models is attributable to deficiencies in the initial conditions. The question of initial condition uncertainty is central to future improvements in NWP. An adjoint model can be used to identify the most significant initial condition sensitivity in a given forecast situation. Since even small initial condition error can be very detrimental in sensitive locations, a targeted improvement in observational capability has the potential for significant increases in forecast skill (higher predictability). Techniques of targeting observations will be demonstrated by assimilating data of various types (obtained in real-time) into operational forecast models and evaluating the impact on forecast skill.

APPROACH:

The scientific approach includes the following elements:
(1) Develop objective adjoint-based techniques to identify critical locations of initial condition sensitivity, and form conceptual models which describe error growth and predictability.
(2) Obtain atmospheric observations in field experiments to determine the impact of atmospheric observations in "target" and "null" (non-sensitive) areas on forecast skill.
(3) Evaluate the impact of targeted observational data with data assimilation and forecast studies in operational forecast situations related to mid-latitude and tropical cyclones.
(4) Develop guidelines for sampling strategies to be used in real-time targeting situations, and requirements for improvements to permanent observing systems, which are likely to provide maximum benefit, as measured by increased forecast skill in situations of importance to Navy operations.

WORK COMPLETED:

Techniques for adaptive observations were tested during the Fronts and Atlantic Storm Track Experiment (FASTEX), field phase in January and February 1997 (Joly et al. 1997). Five cross-Atlantic (Ireland-Newfoundland) dropsonde targeting missions were performed using the NOAA Gulfstream-IV

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long-range, high-altitude jet. This work represents the first real-time test of adaptive observations in Meteorology. In addition, research studies were performed to examine the impact of moist physics in adjoint models (Langland et al. 1996), and the feasibility of adaptive observations for tropical cyclone prediction (Rohaly et al., 1997, 1998).

RESULTS:

Targeting results from assimilation of data obtained in FASTEX IOPs 17 and 18 are described in Gelaro et al (1997) and Langland et al (1998). In these papers, the skill of adaptive observation methods is shown by assimilating data in target areas, and achieving reductions in forecast error with a nonlinear forecast model. An adjoint model is used to define the target areas, but not to evaluate the impact of the data on forecast skill. The nonlinear model used for this work is fully capable of making highly skillful forecasts, when provided with accurate initial conditions. This is primarily an initial value problem, not one of model resolution, physics, or dynamics. We evaluate and compare the impact of aircraft dropsonde, GOES-8 winds, and rawindsonde observations. Proof of concept includes data impact in target and null areas, and discussion of how target structure relates to synoptic features.

The following excerpt from Langland et al (1998) describes the primary results from FASTEX IOP-18:

A quantitative measure of forecast improvement is provided by change to a statistical measure of forecast error in the verification region (48-63N, 15-30W). The measures used are

$$\varepsilon_{24} = \langle \mathbf{e}_{24}; \mathbf{E}\mathbf{e}_{24} \rangle$$

$$\Delta\varepsilon_{24} = \frac{\varepsilon_{24}^{(exp)} - \varepsilon_{24}^{(\mathrm{cntrl})}}{\varepsilon_{24}^{(\mathrm{cntrl})}}$$

where $\supset_{24}$ is the forecast energy norm, $\mathbf{e}_{24}$ is the model state vector 24 hr forecast error, $\mathbf{E}$ is a matrix of energy weights, and Å$\supset_{24}$ is the percent change in the norm in a new forecast (*exp*) with respect to the control (*cntrl*) forecast.

Initial Conditions	$\supset_{24}$ ($m^2 s^{-2}$)	Å$\supset_{24}$ (%)
Control	0.1717	---
GOES-8 Target	0.1326	-23
GOES-8 Null	0.1686	- 2
GOES-8 Target/East	0.1373	-20
GOES/8 Target/West	0.1643	- 4
G-IV	0.1284	-25
G-IV+GOES/8 Target	0.1065	-38

Table 1: Initial condition impact on the forecast error norm: FASTEX IOP-18, Feb 22/12 UTC - Feb 23/12 UTC. Computed at T79 resolution.

Inclusion of only the G-IV dropsonde data reduces the forecast energy norm by 25 percent (Table 1). The best result (38 percent reduction) is obtained from a combined assimilation of G-IV dropsondes and GOES-8 winds over a large "target" area (45-65N, 10-70W). However, as described above and shown in Fig. 4, most of the positive impact from the GOES-8 winds is due to assimilation in the eastern half of this area (45-65N, 10-40W) which reduces the forecast energy norm by 20 percent. By contrast, the "west" target winds (45-65N, 40-70W) only reduce the forecast energy norm by 4 percent. Finally, assimilation of GOES-8 winds outside the area of 45-65N, 40-70W reduces the forecast energy norm by only 2 percent.

To summarize, the G-IV dropsonde data have a positive impact on 24 hr forecast skill in IOP-18, although the primary target area was only partially sampled. Assimilation of GOES-8 winds (also limited in coverage for this case) in addition to

the G-IV data further reduces the forecast error. The GOES-8 wind data, by itself, has a positive, but smaller, impact than that provided by the G-IV dropsondes.

Assimilation of the G-IV and GOES-8 wind data is *not* expected to remove *all* the forecast error, since: a) even when combined, the G-IV and GOES-8 observations do not provide comprehensive coverage of the target area, and b) part of the forecast error is likely caused by analysis method and forecast model deficiencies.

The results of this study suggest that adjoint singular vector and sensitivity information derived in real-time can provide useful guidance for adaptive observations in forecasts of extratropical cyclones, even though approximations and assumptions are involved in the adjoint targeting procedures. The assimilation of aircraft dropsonde and satellite wind data shows that *model analysis error does occur in areas targeted with adjoint-derived singular vectors,* and the initial condition error in these sensitive locations can control a significant percentage of total forecast error in extratropical cyclone prediction.

IMPACT:

The results of these targeting studies are directly relevant to decisions concerning the value and mix of observations, in forecast situations relevant to Navy operations. For example, assimilation of satellite-derived wind data in target areas is shown to provide a major track correction in a forecast of Hurricane Felix (Rohaly et al., 1998).

TRANSITIONS:

The positive impact obtained from assimilation of GOES-8 winds (described above for FASTEX IOP-18) suggests that it may be beneficial to incorporate these data into the assimilation cycle of operational forecast models, with improvements to initial conditions extending as far as north as 55°N. Studies are underway at NRL / FNMOC to determine if the use of GOES-8 and / or GOES-9 winds in mid-latitudes will be transitioned to operations (these data have already been shown to have a positive impact on forecast skill in tropical regions).

RELATED PROJECTS:

This work on adaptive observations and real-time targeting has involved close collaboration with researchers at other sites in Europe and the United States. In particular, interaction with scientists performing adjoint model development and targeting methodology studies at ECMWF, Meteo France, and NCAR has been extremely useful.

The successful implementation of targeted observing strategies depends on the ability to properly assimilate atmospheric data acquired in critical locations. Projects now underway at NRL involve development of next-generation (adjoint-based) data assimilation procedures that will provide substantial improvement over current analysis methods.

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Web Site: NRL Adaptive Observation Program
http://www.nrlmry.navy.mil/projects/adap.html